Missouri Department of Transportation

Bridge Division

Bridge Design Manual

Section 1.4

Revised 02/08/2004

[Click Here for Index](#)

Index of Unit Stresses

1.4.1 Structural Steel

1.1 Structural Steel (ASTM A709)

AASHTO Table 10.32.1A
AASHTO Table 10.32.3B

All structural steel will be ASTM A709 Grade 36 (Fy = 36 ksi) or Grade 50 (Fy = 50 ksi) except where weathering steel (ASTM A709 Grade 50W steel) is indicated on the Design Layout or in special cases.

ASTM A709 Steel					Available Material	
Grade	**Minimum Yield Strength, Fy (ksi)**	**Allowable Tensile Stress, Ft (ksi)**	**Allowable Bending Stress, Fb (ksi)**	**Allowable Shear Stress, Fv (ksi)**	**Maximum Plate Thickness (inches)**	**Shapes**
36	36	20	20	12	4 (*)	All
50	50	27	27	16	4	All
50W	50	27	27	16	4	All

(*) Thickness of plate up to 8 inches may be used when fabricating bearings using ASTM A709 Grade 36 steel .

The allowable fatigue stress range is based on the fatigue stress cycles. See *AASHTO Table 10.3.1A.*

1.4.1 Structural Steel

1.2 Fatigue in Structural Steel

AASHTO Table 10.3.2A
AASHTO Table 10.3.1A

Steel structures subjected to continuous reversal of loads are to be designed for fatigue loading.

ADTT, Average Daily Truck Traffic (one direction), shall be indicated on the design layout. Based on ADTT, the fatigue case and corresponding stress cycles can be obtained from *AASHTO Table 10.3.2A.*

When Case I fatigue is considered, it is necessary to check fatigue due to truck loading for both the 2,000,000 and over 2,000,000 stress cycles. For the over 2,000,000 stress cycles, the moment distribution factor for all stringers or girders (for fatigue stresses only) will be based on **one** lane loaded. For truck loading 2,000,000 cycles and lane loading 500,000 cycles, use the moment distribution factor based on two or more traffic lanes (same as for design moment).

The number of cycles to be used in the fatigue design is dependent on the case number and type of load producing maximum stress as indicated in *AASHTO Table 10.3.2A.*

The allowable fatigue stress range based on the fatigue stress cycles can be obtained from *AASHTO Table 10.3.1A.*

The type of live load used to determine the number of cycles will be the type of loading used to determine the maximum stress at the point under consideration.

In continuous beams, the maximum stresses may be produced by the truck loading at some points, but by lane loading at other points. However, if the lane loading governs, then the longitudinal members should also be checked for truck loading.

Only live loading and impact stresses need to be considered when designing for fatigue.

Fatigue criteria applies only when the stress range is one of tension to tension or reversal. The fatigue criteria does not apply to the stress range from compression to compression.

All fracture critical structures, those which consist of only one or two main carrying members, trusses or single box girders, shall be considered as non-redundant structures. Use the appropriate table which accompanies these structures.

2.1 Reinforced Concrete

Classes of Reinforced Concrete

Listed below are the classes of concrete for each type or portion of structure:

Box Culverts	B-1
Retaining Walls	B or B-1
Superstructure (General)	B-2
Curbs and Parapets	B-1
Safety Barrier Curbs	B-1
Median Barrier Curbs	B-1
Sidewalks	B-2
Raised Median	B-2
Slabs	B-2
Box Girders	B-2
Deck Girders	B-2
Prestressed Precast Panels	A-1
Prestressed I - Girders	A-1
Prestressed Double -Tee Girders	A-1
Integral End Bents (Above lower construction joint)	B-2
Semi-Deep Abutments (Above construction joint under slab)	B-2
Substructure (General)	B (*)
Integral End Bents (Below lower construction joint)	B
Semi-Deep Abutments (Below construction joint under slab)	B
Intermediate Bents	B
Columns	B (*)
Intermediate Bent Columns, End Bents (Below construction joint at bottom of slab) in Cont. Conc. Slab Bridges	B-1
Footings	B
Drilled Shafts	B-2
Cast-In-Place Pile	B-1

(*) *For continuous concrete slab bridges or in special cases when a stronger concrete is deemed necessary by the designer, use class B-1 for columns and end bents below construction joint at bottom of slab.*

Unit Stresses of Reinforced Concrete

Class of Concrete	Aggregate Maximum size (Inches)	Cement Factor (barrels per cubic yard)	f'c (psi)	fc (psi)	n (*)
A-1	1	1.6 (Min.)	5,000	2,000	6
B	1	1.4 (Min.)	3,000	1,200	10
B-1	1	1.6 (Min.)	4,000	1,600	8
B-2	1	1.875 (Min.)	4,000	1,600	8

(*) Values of n for computations of strength only.

Allowable Stresses of Reinforcing Steel

Tensile stress in reinforcement at service loads, fs:

AASHTO 8.15.2.2

Reinforcing Steel (Grade 40) fs = 20,000 psi
Reinforcing Steel (Grade 60) fs = 24,000 psi

For compression stress in beams, see *AASHTO Article 8.15.3.5.*

For compression stress in columns, see *AASHTO Article 8.15.4.*

For fatigue stress limit, see *AASHTO Article 8.16.8.3.*

1.4.2 Reinforced Concrete

2.2 Fatigue In Reinforcing Steel

AASHTO 8.16.8.1, 8.16.8.2

For flexural members designed with reference to load factors and strengths by Strength Design Method, stresses at service load shall be limited to satisfy the requirements for fatigue. Reinforcement should be checked for fatigue at all locations of peak service load stress ranges and at bar cut-off locations except for concrete deck slab in multi-girder applications.

Allowable Stress Range: fr_{allow}

The allowable stress range is found using the equation listed below and the minimum stresses from dead load, live load, and impact based on service loads.

The term minimum stress level f_{min} for this formula indicates the algebraic minimum stress level: tension stress with a positive sign and compression stress with a negative sign.

AASHTO 8.16.8.3

$$fr_{allow} = 21 - 0.33\, f_{min} + 8\, (r/h)$$

where:

- fr_{allow} = allowable stress range (ksi)
- f_{min} = algebraic minimum stress level (ksi):
  positive if tension, negative if compression.
- r / h = ratio of base radius to height of rolled-on transverse deformation;
  if the actual value is not know, 0.3 may be used.

$$fr_{allow} = 23.4 - 0.33\, f_{min} \qquad \text{when } r/h = 0.3$$

Fatigue research has shown that increasing minimum tensile stress results in a decrease in fatigue strength for a tension to tension stresses case. The fatigue strength increases with a bigger compressive stress in a tension to compression stresses case.

Actual Stress Range: fr_{act}

The actual stress range, fr_{act} , is found using dead load, live load, and impact from service loads.

$$fr_{act} = f_{GT} - f_{LT}$$

f_{GT} = greatest tension stress level (ksi), always positive (Not necessary to check compression to compression for fatigue.)

f_{LT} = algebraic least stress level (ksi):

f_{LT} = positive if the least stress is tension
(**tension to tension stresses**)

f_{LT} = negative if the least stress is compression
(**tension to compression stresses**)

2.2 Fatigue In Reinforcing Steel (Cont.)

Tension and Compression Stress Computation

Tension and compression stress are determined by using the following formulae for double reinforced concrete rectangular beams.

fs = tensile stress in reinforcement at service loads (ksi)

Tensile stress $fs = \frac{M}{As\, j\, d}$

f's = compressive stress in reinforcement at service loads (ksi)

Compressive stress $f's = \frac{M}{As\, j\, d} \left| \frac{k - \frac{d'}{d}}{1 - k} \right|$

where:

$$j = \frac{k^2\,(1 - k/3) + 2\rho'\, n\,(k - d'/d)(1 - d'/d)}{k^2 + 2\rho'\, n\,(k - d'/d)}$$ **Eq. 2.2-1**

$$k = \sqrt{2n\,(\rho + \rho'\,(d'/d)) + n^2\,(\rho + \rho')^2} - n\,(\rho + \rho')$$ **Eq. 2.2-2**

ρ = tension reinforcement ratio, $\rho = \frac{As}{b\,d}$

ρ' = compression reinforcement ratio, $\rho' = \frac{A's}{b\,d}$

As = area of tension reinforcement (sq. inch)

A's = area of compression reinforcement (sq. inch)

b = width of beam (inch)

d = distance from extreme compression fiber to centroid of tension reinforcement (inch)

d' = distance from extreme compression fiber to centroid of compression reinf.(inch)

jd = distance from tensile steel to resultant compression (inch)

kd = distance from neutral plane to compression surface (inch)

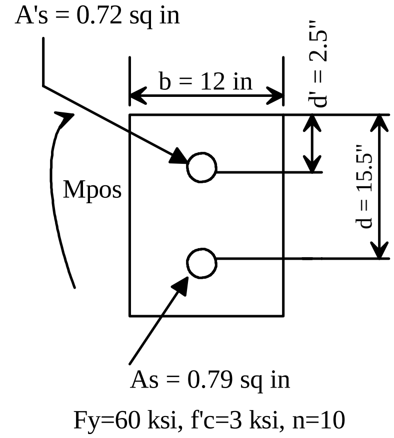
n = ratio of modulus of elasticity of steel to that of concrete (*)

(*) For n value, see the Classes of Reinforced Concrete Table in page 2.1-2 of this section.

Tension and Compression Stress Computation Example

Reinforced Concrete member

Fy = 60 ksi, f'c = 3 ksi, n = 10,
b = 12 in, d = 15.5 in, d' = 2.5 in,
As = 0.79 sq. in, A's = 0.72 sq. in
Mpos = 26.2 kips-ft



ρ = 0.79/(12x15.5) = 0.004247
ρ' = 0.72/(12x15.5) = 0.003871

k = 0.2411 by **Eq. 2.2-2**
j = 0.912 by **Eq. 2.2-1**

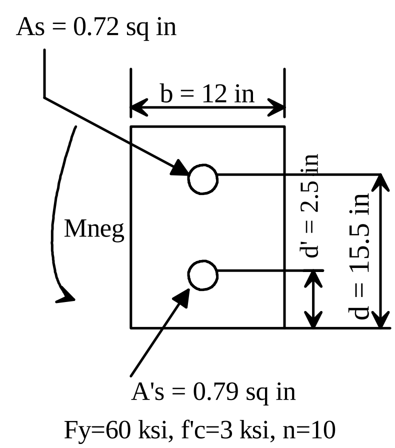
Tensile stress in bottom bar:

$$f_{GT} = f_s = \frac{Mpos}{As\,jd}$$

$$fs = \frac{26.2x12 \text{ (kips-in)}}{(0.79 \text{ sq. in}) (0.912) (15.5 \text{ in})} = 28.15\text{ksi}$$

Reinforced Concrete member

Fy = 60 ksi, f'c = 3 ksi, n = 10,
b = 12 in, d = 15.5 in, d' = 2.5 in,
As = 0.72 sq. in, A's = 0.79 sq. in
Mneg = 20.1 kips-ft



ρ = 0.72/(12x15.5) = 0.003871
ρ' = 0.79/(12x15.5) = 0.004247

k = 0.2314 by **Eq. 2.2-2**
j = 0.914 by **Eq. 2.2-1**

Compressive stress in bottom bar : $f_{LT} = -f's$

$$f'_s = \frac{Mneg}{As\,jd} \times \left| \frac{k - d'/d}{1 - k} \right|$$

$$f'_s = \frac{20.1 \times 12}{(0.72)(0.914)(15.5)} \times \left[\frac{0.2314 - \frac{2.5}{15.5}}{1 - 0.2314} \right] = 2.14 \text{ ksi}$$

Actual Stress Range fr_{act}

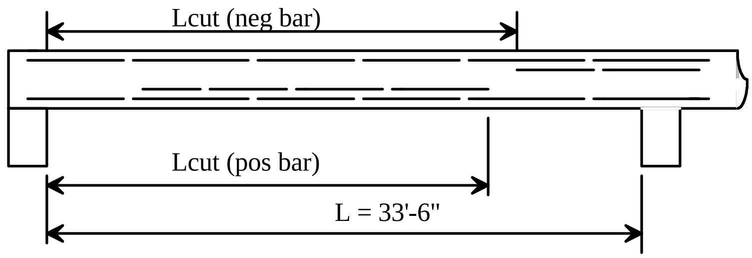
$fr_{act} = f_{GT} - f_{LT}$ = 28. 15 ksi - (- 2.14 ksi) = 30.29 ksi

Application Steel Reinforcement Fatigue

The service load moments for a HS20-44 two-lanes reinforcement concrete slab bridge end span of 33'-6" are as follows:

- Positive bar size = #8 @ 6", Cut-off bar-size = #8 @ 12"
- Negative bar size = #7@ 5", Cut-off bar-size = #7 @ 10"
- Fy = 60 ksi, f 'c = 3000 psi , n = 10

SPAN	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
LOCATION (ft)	10.1	13.4	16.8	20.1	23.5	26.8	30.2	33.5
D + (L + I) (kips-ft)	45.2	46.5	43.4	37.7	26.2	8.8	-11.2	-25.9
D - (L + I) (kips-ft)	11.4	10.2	6.4	0	-8.9	-20.1	-33.9	-54.4



Determine cut-off location for one-half of total **positive reinforcement** to satisfy fatigue stress limitations. The theoretical bar cut-off location due to positive moment is 24 feet (or 71.5% of the span) from left end bent.
Positive moment bar #8 @ 6", cut-off bar size #8 @ 12" (As = 0.79 sq. in).

STEP 1

Compute stress range for bottom bars at **0.7** point

STEP 2

Compute stress range for bottom bars at **0.8** point

$$fs = \frac{Mpos}{As\ jd}$$ Mpos = positive moment, tension in bottom steel

STEP 1:

$$fs = \frac{26.2x12\ (kips\text{-}in)}{(0.79\ sq.in)(0.912)(15.5\ in)}$$

f_{GT} = fs = 28.15 ksi

STEP 2:

$$fs = \frac{8.8x12\ (kips\text{-}in)}{(0.79\ sq.\ in)(0.912)(15.5\ in)}$$

f_{GT} = fs = 9.46 ksi

$$f\,'s = \frac{Mneg}{As\ jd} \times \left[\frac{k - \frac{d'}{d}}{1 - k}\right]$$ Mneg = negative moment, compression in bottom steel

STEP 1:

$$f\,'s = \frac{8.9x12\ (kips\text{-}in)}{0.72x0.914x15.5(cu.\ in)} \times \left[\frac{0.2314 - \frac{2.5}{15.5}}{1 - 0.2314}\right]$$

f_{LT} = - f 's = -0.95 ksi

STEP 2:

$$f\,'s = \frac{20.1x12\ (kips\text{-}in)}{0.72x0.914x15.5(cu.\ in)} \times \left[\frac{0.2314 - \frac{2.5}{15.5}}{1 - 0.2314}\right]$$

f_{LT} = - f 's = - 2.14 ksi

Application Steel Reinforcement Fatigue (Cont.)

STEP 1 (cont.)	STEP 2 (cont.)
Compute stress range for bottom bars at **0.7** point	Compute stress range for bottom bars at **0.8** point

$$\mathbf{fr_{act} = f_{GT} - f_{LT}}$$

fr_{act} = 28.15 - (-0.95) =29.10 ksi	fr_{act} = 9.46 - (-2.14) = 11.50 ksi

$$\mathbf{fr_{allow} = 23.4 - 0.33\, f_{min}}$$

fr_{allow} = 23.4 - 0.33(-0.95) = 23.71 ksi	fr_{allow} = 23.4 - 0.33(-2.14) = 24.11 ksi

Check: $fr_{act} < fr_{allow}$?

fr_{act} = 29.1 ksi > 23.7 ksi = fr_{allow}	fr_{act} = 11.5 ksi < 24.1 ksi = fr_{allow} , O.K.
Not satisfactory for fatigue at point 0.7 therefore, go to **Step 2.**	Indicates that fatigue is satisfied between 0.7 & 0.8 of span, therefore go to **Step 3.**

STEP 3 $\mathbf{fr_{diff} = fr_{allow} - fr_{act}}$

fr_{diff} = 23.71 - 29.1 = - 5.39 ksi	fr_{diff} = 24.11 - 11.5 = 12.61 ksi

Interpolate between points to locate cut-off point.

$$\frac{(0.1 \times 33.5 \text{ ft.})}{|12.61 - (-5.39)|} = \frac{x}{|-5.39|}$$

x = 1.0 ft.

Then cut-off location to satisfy fatigue limitations for positive reinforcement: = 0.7x33.5'+1.0' = 24.45' (or 73% of the span) > 24.00' (or 71.5% of the span),
therefore fatigue governs.

AASHTO 8.24.1.2

The largest of

$15d_b$ = 15" = 1.25'
L/20 = 33.5'/20 = 1.68' .... governs
Section effective d = 15.5" = 1.29'

Then actual cut-off location: = 24.45' + 1.68' = 26.2', say 26.25'

Lcut (#8 pos bar) = 26' - 3" (from left end bent)

Note: Positive moment bar cut-off due to fatigue located from left end bent as shown in page 2.2-4 of this section.

Application Steel Reinforcement Fatigue (Cont.)

Determine cut-off location for one-half of total **negative reinforcement** to satisfy fatigue stress limitations. The theoretical bar cut-off location due to negative moment is at 28'-4" (or 84.5% of the span) from left end bent. Negative moment bars #7 @ 5", cut-off bar size #7 @ 10" (As = 0.72 sq. in).

STEP 1

Compute stress range for top bars at **0.8** point

STEP 2

Compute stress range for top bars at **0.7** point

$$fs = \frac{Mneg}{As\,jd}$$

where: Mneg = negative moment, tension in top steel

Step 1:

$$fs = \frac{20.1x12(\text{kips-in})}{(0.72\text{ sq. in})(0.914)(15.5\text{ in})}$$

f_{GT} = fs = 23.65 ksi

Step 2:

$$fs = \frac{8.9x12\ (\text{kips-in})}{(0.72\text{ sq. in})(0.914)(15.5\text{in})}$$

f_{GT} = fs = 10.47 ksi

$$f\,'s = \frac{Mpos}{As\,jd} \times \left[\frac{k - \frac{d\,'}{d}}{1 - k}\right]$$

where: Mpos = positive moment, compression in top steel

Step 1:

$$f\,'s = \frac{8.8x12\ (\text{kips-in})}{(0.79\text{ sq. in})(0.912)(15.5\text{ in})} \times \left[\frac{0.241 - \frac{2.5}{15.5}}{1 - 0.241}\right]$$

f_{LT} = -f 's = - 0.99 ksi

Step 2:

$$f\,'s = \frac{26.2x12\ (\text{kips-in})}{(0.79\text{ sq. in})(0.912)(15.5\text{ in})} \times \left[\frac{0.241 - \frac{2.5}{15.5}}{1 - 0.241}\right]$$

f_{LT} = -f 's = - 2.96 ksi

$$\mathbf{fr_{act} = f_{GT} - f_{LT}}$$

Step 1: fr_{act} = 23.65-(-0.99) =24.64 ksi

Step 2: fr_{act} =10.47-(-2.96) = 13.43 ksi

$$\mathbf{fr_{allow} = 23.4 - 0.33\,(f_{min})}$$

Step 1: fr_{allow} = 23.4 - 0.33(-0.99) = 23.73 ksi

Step 2: fr_{allow} = 23.4 - 0.33(-2.96) = 24.38 ksi

Check: $fr_{act} < fr_{allow}$?

Step 1: fr_{act} = 24.6 ksi > 23.4 ksi = fr_{allow}

Not satisfactory for fatigue at point 0.8 therefore go to **Step 2.**

Step 2: fr_{act} = 13.4 ksi < 24.3 ksi = fr_{allow} , O. K.

Indicates that fatigue is satisfied between 0.7 & 0.8 of span, therefore go to **Step 3.**

Application Steel Reinforcement Fatigue (Cont.)

STEP 3 $\mathbf{fr_{diff} = fr_{allow} - fr_{act}}$

At **0.8** point

fr_{diff} = 23.73 - 24.64 = - 0.91 ksi

At **0.7** point

fr_{diff} = 24.38 - 13.43 = 10.95 ksi

Interpolate between points to locate cut-off point.

$$\frac{0.1 \times 33.5 ft.}{|(-0.91) - 10.95|} = \frac{x}{|10.95|}$$

x = 3.1 ft

Then cut-off location to satisfy fatigue limitations for negative reinforcement:
= 0.7x33.5'+3.1' = 26.55' (or 79% of the span) < 28.33' (or 84.5% of the span) therefore fatigue governs.

AASHTO 8.24.1.2

The largest of

$15d_b$ = 15x0.875" = 1.09'
L/20 = 33.5'/20 = 1.68' .... governs
Effective depth = 15.5" = 1.29'

Then actual cut-off location: = 26.55' - 1.68' = 24.8' , say 24.75'

Lcut (#7 neg bar) = 24' - 9" (from left end bent)

Note: Negative moment bar cut-off due to fatigue located from left end bent as shown in page 2.2-4 of this section.

1.4.3 Foundations

3.1 Spread Footings

The allowances shown below are intended as a rough guide only, subject to allowable bearing as required on the Design Layout.

Material	**Allowable Bearing (tons/sq ft)**
soils - clay, loam, etc. clay and boulders cemented gravel	See Design Layout
soft shale	6 or under
hard shale	over 6 (*****)
rock	12.0 (******)

(*) Maximum of 8 tons/sq. ft.

(**) Maximum of :
15.0 tons/sq. ft. for spread footings;
30.0 tons/sq. ft. for pedestal piles.
Consult the Structural Project Manager for loads over 12 tons per sq. ft.

3.2 Piling

Pile Type	*Pile Size*	*Allowable Capacities*
Structural Steel	HP 10 x 42	56 tons (*)
Structural Steel	HP 12 x 53	70 tons (*)
Structural Steel	HP 14 x 73	97 tons (*)
Cast-in Place Concrete	14 in. ϕ	30 tons (*)
Cast-in Place Concrete	20 in. ϕ	40 tons (*)
Cast-in Place Concrete	24 in. ϕ	48 tons (*)

(*) *The allowable pile capacities shown in the Table are used for the bridges in Seismic Performance Category A. See Seismic Design Section for analysis of bearing pile capacity in Seismic Performance Categories B, C & D.*

(**) The allowable pile capacities shown in the Table are used for the bridges in Seismic Performance Category A when boring data (SPT blow count, soil descriptions and water table) are not provided. If these data are provided, the allowable pile capacity is equal to the ultimate pile capacity from "SPILE" program divided by a safety factor of 3.5. For Seismic Categories B, C & D, the allowable pile capacity is equal to the ultimate pile capacity from "SPILE" program divided by a safety factor of 2.0, see Seismic Design Section for the detail information.